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International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : H04N

A2

(11) International Publication Number: WO 00/46979

(43) International Publication Date: 10 August 2000 (10.08.00)

(21) International Application Number: PCT/US00/00516

(22) International Filing Date: 4 February 2000 (04.02.00)

(30) Priority Data:
60/118,745 5 February 1999 (05.02.99) US

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(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: CCD ARRAY AS A MULTIPLE-DETECTOR IN AN OPTICAL IMAGING APPARATUS

(57) Abstract

A scanner assembly for a laser imaging apparatus comprises a plurality of collimators disposed in an arc around an opening in which an object to be scanned is disposed; a plurality of fiber optic cables, each having one end being associated with a respective collimator; a light tight enclosure; and a CCD array disposed within the enclosure and disposed at the other ends of the fiber optic cables to detect light picked up by the collimators and transmitted by the fiber optic cables.

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CCD ARRAY AS A MULTIPLE-DETECTOR IN AN OPTICAL IMAGING APPARATUS

FIELD OF THE INVENTION

The present invention relates to optical imaging apparatus and more particularly to imaging devices that use a charge-coupled device(CCD).

BACKGROUND OF THE INVENTION

Charge-coupled devices (CCD's) can be be individual devices or, more commonly, individuals cells or pixels arranged in an array, either as a linear array or as a X-Y matrix. With a suitable optical lens, the CCD is commonly used as a sensor for video cameras. The CCD usually has a spectral response in the visible region, 400-700nm, and typically extends into the near infrared region, 700-1100nm.

Conventional usage primarily focuses on using the CCD as the sensing element of a video camera that produces an electronic image of a field of view. The interval between refreshing the CCD array and sampling the accumulated charge is sometimes referred to as the integration interval. In typical video formats, the integration interval is the result of the vertical frame rate, typically 50 or 60 times per second for an integration interval of 20 and 16.7 milliseconds(ms) respectively.

In some imaging situations, the level of light that is available is extremely low. There are several devices that convert radiant energy into electrical energy. Conventional

sensors for low light levels are photomultiplier tubes(PMT) and micro channel plates(MCP) that provide amplification by secondary emission of electrons. In a PMT, a photosensitive cathode releases electrons when photons impinge upon it, i.e., photoemission. The positive bias applied to the elements of a PMT, the dynodes, attract the negative charge electrons, e^-, emitted by the photocathode. When the electrons strike the dynodes, they cause a secondary release of addition electrons, i.e., secondary emission. These additional electrons subsequently strike dynodes that have a higher positive bias and release additional electrons. This avalanche effect continues until the final dynode is involved. The avalanche causes an amplification of the single photon striking the photocathode. Typically, a 12-stage photomultiplier has an amplification of approximately 17 million. A single photon results in the release of approximately 17 millions electrons. The pulse has a time duration of approximately 5 nanoseconds resulting in a peak current flow of approximately 1 milliampere.

The micro channel plate amplifies the single photon event in a similar manner. Very small diameter holes are fabricated into a plate and then coated with a conductive material. The effect is similar to a PMT. Electrons enter the holes and dislodge other electrons which in turn dislodge even more electrons. The net result is that a single electron initiates an avalanche of electrons and signal amplification occurs. When used alone or in cascade, signal gains of 10^4 to 10^7 are achieved with temporal resolution of approximately 100 picoseconds. Spatial resolution is limited by the channel

spacing, typically 9μm-diameter channels on 10μm centers. Resolution of this type of design is approximately 16 line pairs/mm. The anode side of the MCP is coated onto the inside of a glass envelope and is made of a photoemissive material. When the accelerated photons impinge on the coating a flash of light is given off.

In a MCP CCD array, the CCD element is coupled to the anode end of the MCP and light flashes are directed to the pixels in the CCD array. A signal as small as a single photon can result in a detectable event. In some designs two MCP's are cascaded to more than double the sensitivity of the CCD system. The CCD array is fabricated with parallel conducting strips in one direction and p^+ channel stops at right angles. Electron-hole pairs are created when light is incident on the p-type silicon. The charges, representing picture-element signals, are stored in potential wells under depletion-biased electrodes, i.e., the picture elements(pixels) in the array. The charges are transferred by applying a positive pulse to the adjacent electrodes. The whole image is transferred to a storage raster. Each horizontal line is read out of the storage raster in sequence to provide an output signal. It is possible to read the signal from individual pixels, and this is desirable under certain circumstance.

The rate at which the data is read out from a CCD array has important ramifications. If the CCD is not read for a long length of time and the incident light is very weak, the stored charge will increase over time and a usable image can result.

While an array of PMT's could be fabricated to emulate the detection capabilities of an intensified CCD, there are physical considerations that make this approach unattractive. One advantage of an intensified CCD is the small size required for the detector area. A large number of pixels can be fitted into an area less than one-square centimeter. If a bundle of fiber optic cables are placed in front of the MCP input face and an appropriate lens is used to focus the light emitted by the fiber optic cables, a large number of individual fiber optic cables can be monitored by as small as a single pixel per fiber in the array. Because there are hundreds of pixels--512 x 512 pixels are not uncommon--a significant number of individual fiber optic cables can be coupled to a single detector array.

Thus the present invention describes an apparatus and method for using a single CCD array as a detector for one single photonic event as seen by a single input fiber optic cable or significantly more than one photonic event can be monitored by the array.

OBJECTS AND SUMMARY OF THE INVENTION

It is an object of the present invention to use a CCD or an image intensified cooled CCD array as a detector for photonic events occurring in the visible and near infrared portions of the spectrum.

It is another object of the present invention to use a lens to couple the light emerging from a bundle of fiber optic cables onto the input face of an image intensifying device placed in front of a cooled CCD array.

It is another object of the present invention to use a single image intensified cooled CCD array as a detector for one or a plurality of detectors for individuals events.

It is another object of the present invention to use a single image intensified cooled CCD array as an integrating detector whereby photonic events separated in time can be acquired by a single detector array.

In summary, the present invention provides a scanner assembly for a laser imaging apparatus, comprising a plurality of collimators disposed in an arc around an opening in which an object to be scanned is disposed; a plurality of fiber optic cables, each being associated with a respective collimator; and a CCD array disposed at the other ends of the fiber optic cables to detect light picked up by the collimators and transmitted by the fiber optic cables.

These and other objectives of the present invention will become apparent from the following detailed description.

BRIEF DESCRIPTIONS OF THE DRAWINGS

Figure 1 is a schematic perspective view of a detector assembly in accordance with the present invention, showing a CCD array with a N x N matrix of pixels, a focusing lens, an optical filter, a manifold for holding the fiber optic bundle and a bundle of fiber optic cables.

Figure 2 is schematic perspective view of a CCD array showing a portion being illuminated by a ray of light.

Figure 3 is a schematic block diagram of a CCD camera including an electronic circuit to control and read a CCD array.

Figure 4 is a schematic view of a data acquisition system using one or more fiber optic cables to couple light collected by individual collimators positioned as an array encircling a breast in an optical scanning application.

Figure 5 is an arrangement of the ends of the fiber optic cables at the CCD array.

DETAILED DESCRIPTION OF THE INVENTION

An assembly R for using a CCD array 2 as a photodetector in a computed tomography laser mammography apparatus is disclosed in Figure 1. Light collected from a scanning chamber is transmitted by a plurality of fiber optic cables 4 held together by a suitable manifold 6 to position the fiber optic cables 4 in a specific pattern in front of the CCD array 2. The manifold 6 is a support comprising a matrix of holes 7 each adapted to receive and support therein a fiber optic cable 4. Light rays 9 emitting from the ends of the fiber optic cables 4 are directed to the CCD array 2. Optical filters 8 may be used to selectively tune the wavelengths transmitted by the optic fibers before they impinge on the CCD array 2. A single filter 8 can be used for the whole set of bundle of fiber optic cables instead of a single filter for each fiber. The filter 8 may be a bandpass filter to pass only the desired range of wavelengths. The filter 8 may also be a cutoff filter to pass only the desired range of wavelengths greater or less than a cutoff wavelength. The filter 8 is used in fluorescence imaging, as disclosed in U.S. Patent No. 5,952,664. A lens 10 may be used to focus the light from the optic fibers onto the CCD array 2. The lens 10

may be eliminated where the fiber bundle is placed very close to or in contact with a micro channel plate (MCP) 12 used in conjunction with the CCD array 2.

The CCD array 2 comprises individual cells or pixels 14 arranged in an array, either as a linear array or as X-Y matrix. Referring to Fig. 2, a light ray from an optic fiber 4, represented by a footprint 13, illuminates four pixels. The number of pixels illuminated can be controlled by the use of the lens 10. Changing the lens 10 can reduce or expand the number of pixels illuminated. The choice of the lens 10 allows for an area as small as a few pixels, or as large as the area covered by all of the pixels to be illuminated. Each element or pixel of the CCD array acts as an individual sensor responsive to light emitting from a fiber optic cable. The light intensity as seen by the sensor is read and used to reconstruct an image of the object being scanned.

A standard CCD camera 15 used in the present invention is disclosed in Fig. 3. Incoming light 16 transmitted by the fiber optic cables 4 is directed to an optic lens 18 that distributes the incoming light unto the CCD array 2. A shutter 20 can be used to control the light radiating on the CCD array 2. A window seal 22 provides a light-tight enclosure. A camera control logic and power supply 24 is used to control the CCD array 2. DC voltage 26, serial clock drive signals 28 and parallel clock drive signals 30 are connected to the CCD array 2. A low noise preamplifier 32 is used to amplify the CCD pixel signals. An analog processing and analog-to-digital conversion is provided by block 34. Pixel output data 36 is coupled to a computer interface circuit 38,

which is a high precision video frame grabber, such as that available from La Vision Gmbh, Goettingen, Germany, Pico Star High Resolution - Product Imager. The camera control logic and power supply 24 provides a camera status signal 40. The computer interface circuit 38 provides camera commands 42. The circuit 38 provides the interface between a computer 44 and the CCD array 2. The computer 44 is used to manipulate the CCD information to create an image of the breast as seen by the CCD array. The computer 44 can also extract information from only selected pixels within the CCD array. The CCD array 2 is cooled by a thermo-electric cooler 46 or other suitable coolers. A charge intensified device (CID) or ceramic metal oxide semiconductor (CMOS)array, cooled or intensified, may be used in lieu of the CCD array.

Referring to Fig. 4, in a typical breast scanning application, a breast (not shown) is to be suspended in an opening 50. A laser scanner 52 comprises a source of laser beam 54 for impinging on the breast. Light exiting from the breast is picked up by the collimators 56 directed to the areas of the breast from which light is exiting. The collimators are disposed in an arc around the breast and supported by a structure 57 rotatable 360 degrees about an axis centered on the opening 50 center. The fiber optic cables are identical in length and provide enough slack to allow the rotation of the structure 57. Each collimator is coupled to a fiber optic cable. The scanner, including the collimators 56 and the laser beam 54, is rotated as a unit around the breast in steps through several equal angular displacements until a complete circle is traversed. At each

angular position, the collimators pick up any light exiting from the breast and couple the light to the respective fiber optic cables. The group of fiber optic cables 4 is held by the manifold 6. The fiber optic cables 4 direct the light unto the micro channel plate 12 of a CCD array 2 forming the input to the MCP CCD camera 15. The computer 44 processes the light detected by the camera to generate an image of the breast.

The fiber optic cables 4 are arranged in the manifold 6 such that adjacent fiber ends at the collimators are not adjacent at the other end at the CCD array. This arrangement is designed to provide minimum cross-talk between the fibers. In a laser imaging apparatus using 84 detectors, each being associated with a respective collimator and fiber optic cable, where collimator 56 is designated as detector 1 and collimator 60 is detector 84, an example of an arrangement of the ends of fiber optic cables at the CCD array is disclosed in Fig. 5. Note that adjacent fibers at the collimator end are not adjacent at the manifold 6.

Use of collimators in a laser imaging apparatus is described in application serial no. 08/963,760, filed November 4, 1997, hereby incorporated by reference. Use of fiber optic cables to transmit light captured by the collimators to remote detectors is described in application serial no. 09/199,440, filed November 25, 1998, hereby incorporated by reference. Examples of laser imaging machines are disclosed in U.S. Patent No. 5,692,511 and application serial no. 09/199,440, hereby incorporated by reference. A method for reconstructing an image from data provided by an array of detectors is

described in application serial no. 08/979,624, filed November 28, 1997, hereby incorporated by reference. Determination of the perimeter of the breast being scanned, which is used in image reconstruction, is described in application serial nos. 08/965,148 and 08/965,149, hereby incorporated by reference.

While this invention has been described as having preferred design, it is understood that it is capable of further modification, uses and/or adaptations following in general the principle of the invention and including such departures from the present disclosure as come within known or customary practice in the art to which the invention pertains, and as may be applied to the essential features set forth, and fall within the scope of the invention or the limits of the appended claims.

We claim:

1. A scanner assembly for a laser imaging apparatus, comprising:

a) a plurality of collimators disposed in an arc around an opening in which an object to be scanned is disposed;

b) a plurality of fiber optic cables, each having one end being associated with a respective collimator;

c) a light-tight enclosure; and

d) a CCD array disposed within said enclosure and disposed at the other ends of said fiber optic cables to detect light picked up by said collimators and transmitted by said fiber optic cables.

2. A scanner assembly as in claim 1, wherein:

a) said CCD array includes a micro channel plate.

3. A scanner assembly as in claim 1, and further comprising:

a) a support to position said other ends of said fiber optic cables in front of said CCD array in a pattern.

4. A scanner assembly as in claim 3, wherein:

a) said support is a manifold including a matrix of holes to receive therein a respective fiber optic cable.

5. A scanner assembly as in claim 3, wherein:

a) said other ends of said fiber optic cables are arranged in such a way that adjacent ends at said collimators are not adjacent at said support.

6. A scanner assembly as in claim 1, and further comprising:

a) a lens disposed between said CCD array and said

other ends of said fiber optic cables to focus the light from the other ends of said fiber optic cables onto said CCD array.

7. A scanner assembly as in claim 1, and further comprising:

a) a lens disposed between said CCD array and said other ends of said fiber optic cables to focus the light from the other ends of said fiber optica cables onto a selected portion of said CCD array.

8. A scanner assembly as in claim 1, and further comprising:

a) a filter disposed between said CCD array and said other ends of said fiber optic cables.

9. A scanner assembly as in claim 8, wherein:

a) said filter is a bandpass filter.

10. A scanner assembly ad in claim 8, wherein:

a) said filter is a cutoff filter.

11. A scanner assembly for a laser imaging apparatus, comprising:

a) a plurality of collimators disposed in an arc around an opening in which an object to be scanned is disposed;

b) a plurality of fiber optic cables, each being associated with a respective collimator; and

c) a CCD camera operably disposed at the other ends of said fiber optic cables to detect light picked up by said collimators and transmitted by said fiber optic cables.

12. A scanner assembly as in claim 11, and further comprising:

a) a support to position said other ends of said

fiber optic cables in a pattern into an optic of said CCD camera.

13. A scanner assembly as in claim 12, wherein:

a) said support is a manifold including a matrix of holes to receive therein a respective fiber optic cable.

14. A scanner assembly for optical imaging, comprising:

a) a plurality of collimators disposed in an arc around an opening in which an object to be scanned is disposed;

b) a plurality of fiber optic cables, one end of each being associated with a respective collimator;

c) a support to secure the opposite ends of said fiber optic cables in a pattern; and

d) a CCD camera operably disposed at the other ends of said fiber optic cables to detect light picked up by said collimators and transmitted by said fiber optic cables.

15. A scanner assembly as in claim 14, wherein:

a) said other ends of said fiber optic cables are arranged in such a way that adjacent ends at said collimators are not adjacent at said support.

16. A method for collecting data for use in image reconstruction of an object being scanned with a laser beam, comprising:

a) providing a laser beam directed to the object being scanned;

b) providing a plurality of collimators disposed in an arc around the object to be scanned to collect light radiating from the object;

c) providing a plurality of fiber optic cables, one

end of each being associated with a respective collimator;

d) bundling together the opposite ends of the fiber optic cables;

e) providing a CCD array to take an image of the bundled ends of the fiber optic cables; and

f) using the image on the CCD array to reconstruct an image of the object.

17. A method as in claim 16, wherein:

a) said bundling is implemented such that adjacent fiber optic cables at the collimators are not adjacent at the other ends.

18. A method as in claim 16, wherein:

a) said bundling is implemented with a manifold to hold the other ends of the fiber optic cables in a pattern.

19. A method as in claim 16, wherein:

a) the fiber optic cables are equal in length.

20. A method as in claim 16, wherein:

a) the CCD array comprises a part of a CCD camera.

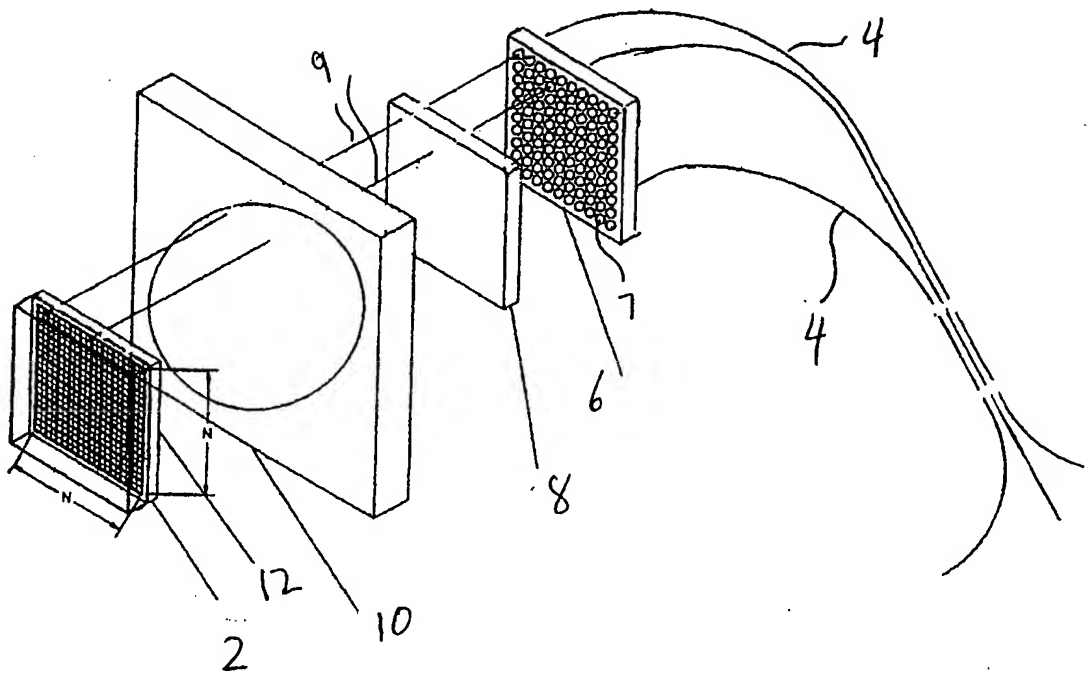

Figure 1

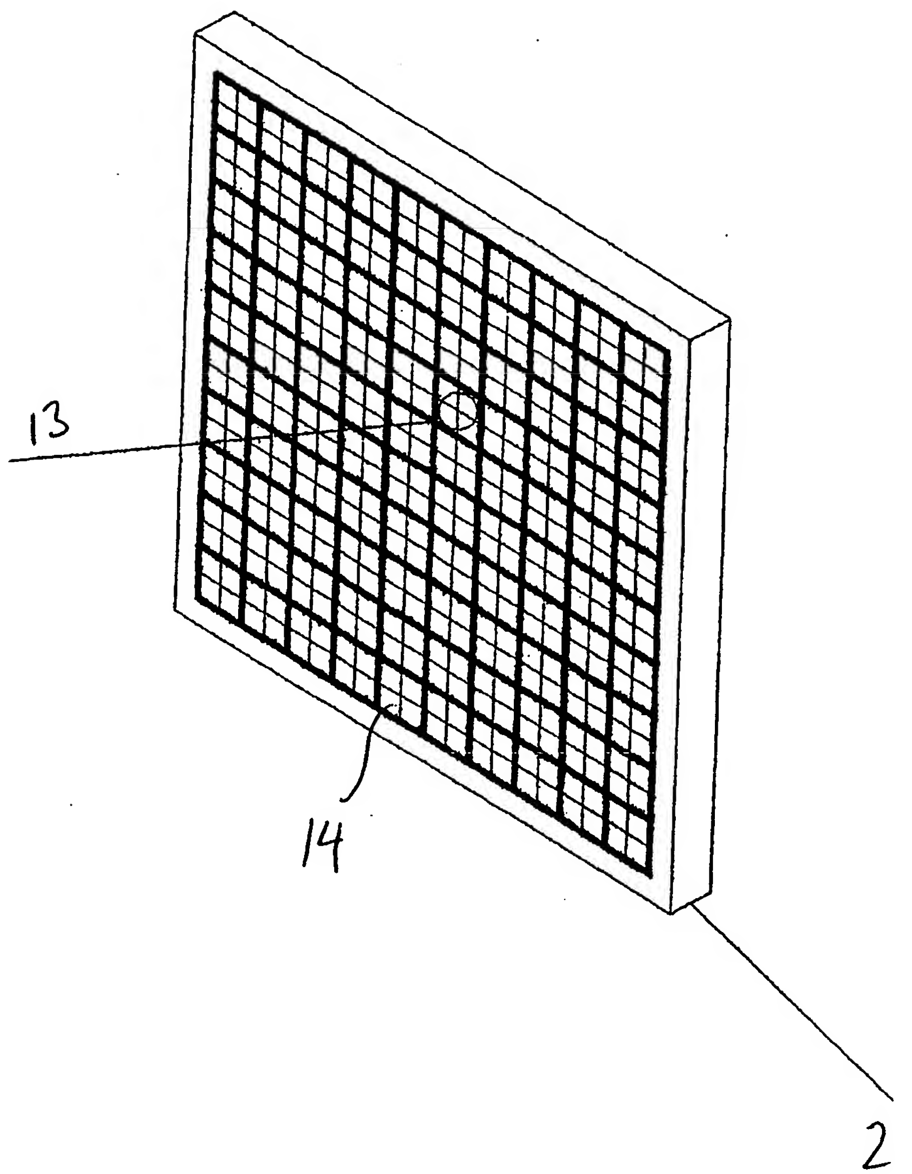

Figure 2

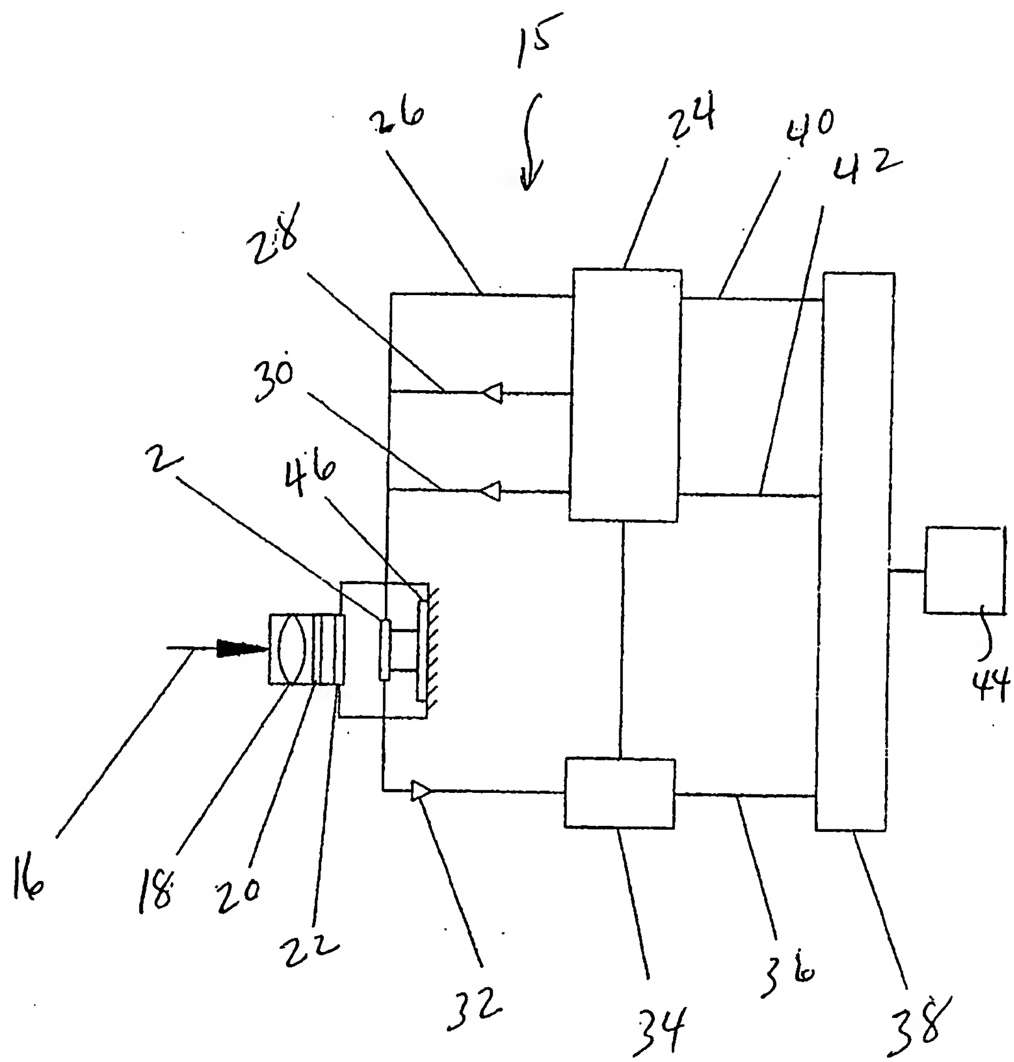

Figure 3

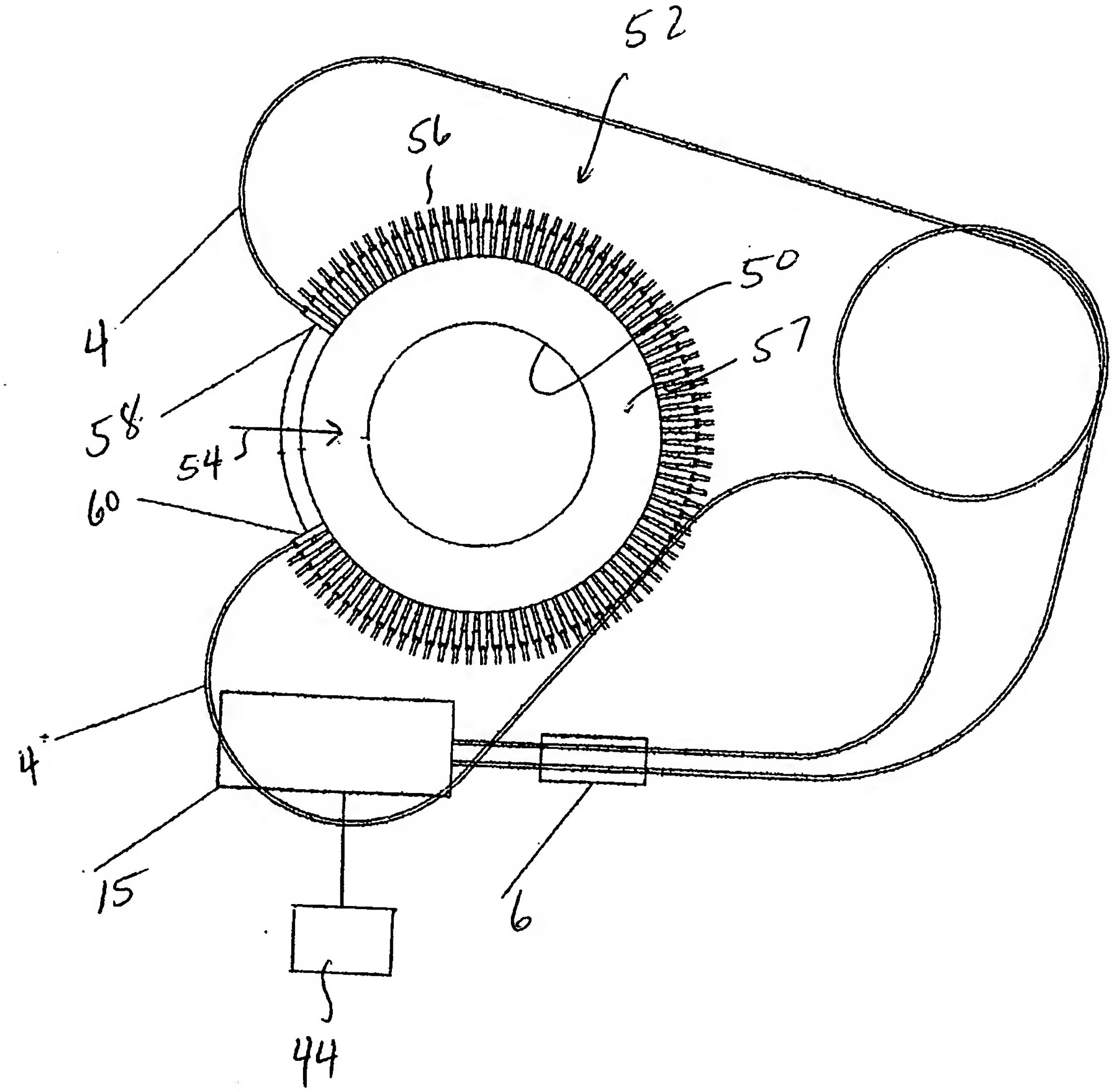

Figure 4

36	9	17	25	33	41	49	57	65	73	REF
5	13	21	29	37	45	53	61	69	77	81
3	11	19	27	35	43	51	59	67	75	83
7	15	23	31	39	47	55	63	71	79	2
6	14	22	30	38	46	54	62	70	78	4
10	18	26	34	42	50	58	66	74	82	8
12	20	28	1	44	52	60	68	76	84	16
24	32	40	48	56	64	72	80	*	*	*

Fig. 5

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

CORRECTED VERSION

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
10 August 2000 (10.08.2000)

PCT

(10) International Publication Number
WO 00/46979 A3

(51) International Patent Classification[7]: A61B 1/04, H04N 3/02, 5/225, G01N 21/64, F21K 2/00

(21) International Application Number: PCT/US00/00516

(22) International Filing Date: 4 February 2000 (04.02.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/118,745 5 February 1999 (05.02.1999) US

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(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

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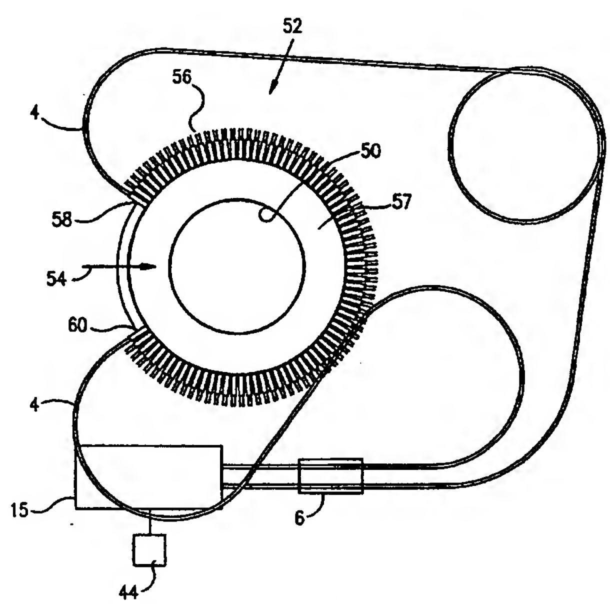

(57) **Abstract:** A scanner assembly for a laser imaging apparatus comprises a plurality of collimators (56) disposed in an arc around an opening in which an object to be scanned is disposed; a plurality of fiber optic cables (4), each having one end being associated with a respective collimator; a light tight enclosure; and a CCD array disposed within the enclosure (15) and disposed at the other ends of the fiber optic cables to detect light picked up by the collimators and transmitted by the fiber optic cables.

WO 00/46979 A3

(88) **Date of publication of the international search report:**
30 November 2000

(48) **Date of publication of this corrected version:**
30 August 2001

(15) **Information about Correction:**
see PCT Gazette No. 35/2001 of 30 August 2001, Section II

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

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The micro channel plate amplifies the single photon event in a similar manner. Very small diameter holes are fabricated into a plate and then coated with a conductive material. The effect is similar to a PMT. Electrons enter the holes and dislodge other electrons which in turn dislodge even more electrons. The net result is that a single electron initiates an avalanche of electrons and signal amplification occurs. When used alone or in cascade, signal gains of 10^4 to 10^7 are achieved with temporal resolution of approximately 100 picoseconds. Spatial resolution is limited by the channel

spacing, typically 9μm-diameter channels on 10μm centers. Resolution of this type of design is approximately 16 line pairs/mm. The anode side of the MCP is coated onto the inside of a glass envelope and is made of a photoemissive material. When the accelerated photons impinge on the coating a flash of light is given off.

In a MCP CCD array, the CCD element is coupled to the anode end of the MCP and light flashes are directed to the pixels in the CCD array. A signal as small as a single photon can result in a detectable event. In some designs two MCP's are cascaded to more than double the sensitivity of the CCD system. The CCD array is fabricated with parallel conducting strips in one direction and p^+ channel stops at right angles. Electron-hole pairs are created when light is incident on the p-type silicon. The charges, representing picture-element signals, are stored in potential wells under depletion-biased electrodes, i.e., the picture elements(pixels) in the array. The charges are transferred by applying a positive pulse to the adjacent electrodes. The whole image is transferred to a storage raster. Each horizontal line is read out of the storage raster in sequence to provide an output signal. It is possible to read the signal from individual pixels, and this is desirable under certain circumstance.

The rate at which the data is read out from a CCD array has important ramifications. If the CCD is not read for a long length of time and the incident light is very weak, the stored charge will increase over time and a usable image can result.

While an array of PMT's could be fabricated to emulate the detection capabilities of an intensified CCD, there are physical considerations that make this approach unattractive. One advantage of an intensified CCD is the small size required for the detector area. A large number of pixels can be fitted into an area less than one-square centimeter. If a bundle of fiber optic cables are placed in front of the MCP input face and an appropriate lens is used to focus the light emitted by the fiber optic cables, a large number of individual fiber optic cables can be monitored by as small as a single pixel per fiber in the array. Because there are hundreds of pixels--512 x 512 pixels are not uncommon--a significant number of individual fiber optic cables can be coupled to a single detector array.

Thus the present invention describes an apparatus and method for using a single CCD array as a detector for one single photonic event as seen by a single input fiber optic cable or significantly more than one photonic event can be monitored by the array.

OBJECTS AND SUMMARY OF THE INVENTION

It is an object of the present invention to use a CCD or an image intensified cooled CCD array as a detector for photonic events occurring in the visible and near infrared portions of the spectrum.

It is another object of the present invention to use a lens to couple the light emerging from a bundle of fiber optic cables onto the input face of an image intensifying device placed in front of a cooled CCD array.

It is another object of the present invention to use a single image intensified cooled CCD array as a detector for one or a plurality of detectors for individuals events.

It is another object of the present invention to use a single image intensified cooled CCD array as an integrating detector whereby photonic events separated in time can be acquired by a single detector array.

In summary, the present invention provides a scanner assembly for a laser imaging apparatus, comprising a plurality of collimators disposed in an arc around an opening in which an object to be scanned is disposed; a plurality of fiber optic cables, each being associated with a respective collimator; and a CCD array disposed at the other ends of the fiber optic cables to detect light picked up by the collimators and transmitted by the fiber optic cables.

These and other objectives of the present invention will become apparent from the following detailed description.

BRIEF DESCRIPTIONS OF THE DRAWINGS

Figure 1 is a schematic perspective view of a detector assembly in accordance with the present invention, showing a CCD array with a N x N matrix of pixels, a focusing lens, an optical filter, a manifold for holding the fiber optic bundle and a bundle of fiber optic cables.

Figure 2 is schematic perspective view of a CCD array showing a portion being illuminated by a ray of light.

Figure 3 is a schematic block diagram of a CCD camera including an electronic circuit to control and read a CCD array.

Figure 4 is a schematic view of a data acquisition system using one or more fiber optic cables to couple light collected by individual collimators positioned as an array encircling a breast in an optical scanning application.

Figure 5 is an arrangement of the ends of the fiber optic cables at the CCD array.

DETAILED DESCRIPTION OF THE INVENTION

An assembly R for using a CCD array 2 as a photodetector in a computed tomography laser mammography apparatus is disclosed in Figure 1. Light collected from a scanning chamber is transmitted by a plurality of fiber optic cables 4 held together by a suitable manifold 6 to position the fiber optic cables 4 in a specific pattern in front of the CCD array 2. The manifold 6 is a support comprising a matrix of holes 7 each adapted to receive and support therein a fiber optic cable 4. Light rays 9 emitting from the ends of the fiber optic cables 4 are directed to the CCD array 2. Optical filters 8 may be used to selectively tune the wavelengths transmitted by the optic fibers before they impinge on the CCD array 2. A single filter 8 can be used for the whole set of bundle of fiber optic cables instead of a single filter for each fiber. The filter 8 may be a bandpass filter to pass only the desired range of wavelengths. The filter 8 may also be a cutoff filter to pass only the desired range of wavelengths greater or less than a cutoff wavelength. The filter 8 is used in fluorescence imaging, as disclosed in U.S. Patent No. 5,952,664. A lens 10 may be used to focus the light from the optic fibers onto the CCD array 2. The lens 10

may be eliminated where the fiber bundle is placed very close to or in contact with a micro channel plate (MCP) 12 used in conjunction with the CCD array 2.

The CCD array 2 comprises individual cells or pixels 14 arranged in an array, either as a linear array or as X-Y matrix. Referring to Fig. 2, a light ray from an optic fiber 4, represented by a footprint 13, illuminates four pixels. The number of pixels illuminated can be controlled by the use of the lens 10. Changing the lens 10 can reduce or expand the number of pixels illuminated. The choice of the lens 10 allows for an area as small as a few pixels, or as large as the area covered by all of the pixels to be illuminated. Each element or pixel of the CCD array acts as an individual sensor responsive to light emitting from a fiber optic cable. The light intensity as seen by the sensor is read and used to reconstruct an image of the object being scanned.

A standard CCD camera 15 used in the present invention is disclosed in Fig. 3. Incoming light 16 transmitted by the fiber optic cables 4 is directed to an optic lens 18 that distributes the incoming light unto the CCD array 2. A shutter 20 can be used to control the light radiating on the CCD array 2. A window seal 22 provides a light-tight enclosure. A camera control logic and power supply 24 is used to control the CCD array 2. DC voltage 26, serial clock drive signals 28 and parallel clock drive signals 30 are connected to the CCD array 2. A low noise preamplifier 32 is used to amplify the CCD pixel signals. An analog processing and analog-to-digital conversion is provided by block 34. Pixel output data 36 is coupled to a computer interface circuit 38,

which is a high precision video frame grabber, such as that available from La Vision Gmbh, Goettingen, Germany, Pico Star High Resolution - Product Imager. The camera control logic and power supply 24 provides a camera status signal 40. The computer interface circuit 38 provides camera commands 42. The circuit 38 provides the interface between a computer 44 and the CCD array 2. The computer 44 is used to manipulate the CCD information to create an image of the breast as seen by the CCD array. The computer 44 can also extract information from only selected pixels within the CCD array. The CCD array 2 is cooled by a thermo-electric cooler 46 or other suitable coolers. A charge intensified device (CID) or ceramic metal oxide semiconductor (CMOS)array, cooled or intensified, may be used in lieu of the CCD array.

Referring to Fig. 4, in a typical breast scanning application, a breast (not shown) is to be suspended in an opening 50. A laser scanner 52 comprises a source of laser beam 54 for impinging on the breast. Light exiting from the breast is picked up by the collimators 56 directed to the areas of the breast from which light is exiting. The collimators are disposed in an arc around the breast and supported by a structure 57 rotatable 360 degrees about an axis centered on the opening 50 center. The fiber optic cables are identical in length and provide enough slack to allow the rotation of the structure 57. Each collimator is coupled to a fiber optic cable. The scanner, including the collimators 56 and the laser beam 54, is rotated as a unit around the breast in steps through several equal angular displacements until a complete circle is traversed. At each

angular position, the collimators pick up any light exiting from the breast and couple the light to the respective fiber optic cables. The group of fiber optic cables 4 is held by the manifold 6. The fiber optic cables 4 direct the light unto the micro channel plate 12 of a CCD array 2 forming the input to the MCP CCD camera 15. The computer 44 processes the light detected by the camera to generate an image of the breast.

The fiber optic cables 4 are arranged in the manifold 6 such that adjacent fiber ends at the collimators are not adjacent at the other end at the CCD array. This arrangement is designed to provide minimum cross-talk between the fibers. In a laser imaging apparatus using 84 detectors, each being associated with a respective collimator and fiber optic cable, where collimator 56 is designated as detector 1 and collimator 60 is detector 84, an example of an arrangement of the ends of fiber optic cables at the CCD array is disclosed in Fig. 5. Note that adjacent fibers at the collimator end are not adjacent at the manifold 6.

Use of collimators in a laser imaging apparatus is described in application serial no. 08/963,760, filed November 4, 1997, hereby incorporated by reference. Use of fiber optic cables to transmit light captured by the collimators to remote detectors is described in application serial no. 09/199,440, filed November 25, 1998, hereby incorporated by reference. Examples of laser imaging machines are disclosed in U.S. Patent No. 5,692,511 and application serial no. 09/199,440, hereby incorporated by reference. A method for reconstructing an image from data provided by an array of detectors is

described in application serial no. 08/979,624, filed November 28, 1997, hereby incorporated by reference. Determination of the perimeter of the breast being scanned, which is used in image reconstruction, is described in application serial nos. 08/965,148 and 08/965,149, hereby incorporated by reference.

While this invention has been described as having preferred design, it is understood that it is capable of further modification, uses and/or adaptations following in general the principle of the invention and including such departures from the present disclosure as come within known or customary practice in the art to which the invention pertains, and as may be applied to the essential features set forth, and fall within the scope of the invention or the limits of the appended claims.

We claim:

1. A scanner assembly for a laser imaging apparatus, comprising:

a) a plurality of collimators disposed in an arc around an opening in which an object to be scanned is disposed;

b) a plurality of fiber optic cables, each having one end being associated with a respective collimator;

c) a light-tight enclosure; and

d) a CCD array disposed within said enclosure and disposed at the other ends of said fiber optic cables to detect light picked up by said collimators and transmitted by said fiber optic cables.

2. A scanner assembly as in claim 1, wherein:

a) said CCD array includes a micro channel plate.

3. A scanner assembly as in claim 1, and further comprising:

a) a support to position said other ends of said fiber optic cables in front of said CCD array in a pattern.

4. A scanner assembly as in claim 3, wherein:

a) said support is a manifold including a matrix of holes to receive therein a respective fiber optic cable.

5. A scanner assembly as in claim 3, wherein:

a) said other ends of said fiber optic cables are arranged in such a way that adjacent ends at said collimators are not adjacent at said support.

6. A scanner assembly as in claim 1, and further comprising:

a) a lens disposed between said CCD array and said

other ends of said fiber optic cables to focus the light from the other ends of said fiber optic cables onto said CCD array.

7. A scanner assembly as in claim 1, and further comprising:

a) a lens disposed between said CCD array and said other ends of said fiber optic cables to focus the light from the other ends of said fiber optica cables onto a selected portion of said CCD array.

8. A scanner assembly as in claim 1, and further comprising:

a) a filter disposed between said CCD array and said other ends of said fiber optic cables.

9. A scanner assembly as in claim 8, wherein:

a) said filter is a bandpass filter.

10. A scanner assembly ad in claim 8, wherein:

a) said filter is a cutoff filter.

11. A scanner assembly for a laser imaging apparatus, comprising:

a) a plurality of collimators disposed in an arc around an opening in which an object to be scanned is disposed;

b) a plurality of fiber optic cables, each being associated with a respective collimator; and

c) a CCD camera operably disposed at the other ends of said fiber optic cables to detect light picked up by said collimators and transmitted by said fiber optic cables.

12. A scanner assembly as in claim 11, and further comprising:

a) a support to position said other ends of said

fiber optic cables in a pattern into an optic of said CCD camera.

13. A scanner assembly as in claim 12, wherein:

a) said support is a manifold including a matrix of holes to receive therein a respective fiber optic cable.

14. A scanner assembly for optical imaging, comprising:

a) a plurality of collimators disposed in an arc around an opening in which an object to be scanned is disposed;

b) a plurality of fiber optic cables, one end of each being associated with a respective collimator;

c) a support to secure the opposite ends of said fiber optic cables in a pattern; and

d) a CCD camera operably disposed at the other ends of said fiber optic cables to detect light picked up by said collimators and transmitted by said fiber optic cables.

15. A scanner assembly as in claim 14, wherein:

a) said other ends of said fiber optic cables are arranged in such a way that adjacent ends at said collimators are not adjacent at said support.

16. A method for collecting data for use in image reconstruction of an object being scanned with a laser beam, comprising:

a) providing a laser beam directed to the object being scanned;

b) providing a plurality of collimators disposed in an arc around the object to be scanned to collect light radiating from the object;

c) providing a plurality of fiber optic cables, one

end of each being associated with a respective collimator;

d) bundling together the opposite ends of the fiber optic cables;

e) providing a CCD array to take an image of the bundled ends of the fiber optic cables; and

f) using the image on the CCD array to reconstruct an image of the object.

17. A method as in claim 16, wherein:

a) said bundling is implemented such that adjacent fiber optic cables at the collimators are not adjacent at the other ends.

18. A method as in claim 16, wherein:

a) said bundling is implemented with a manifold to hold the other ends of the fiber optic cables in a pattern.

19. A method as in claim 16, wherein:

a) the fiber optic cables are equal in length.

20. A method as in claim 16, wherein:

a) the CCD array comprises a part of a CCD camera.

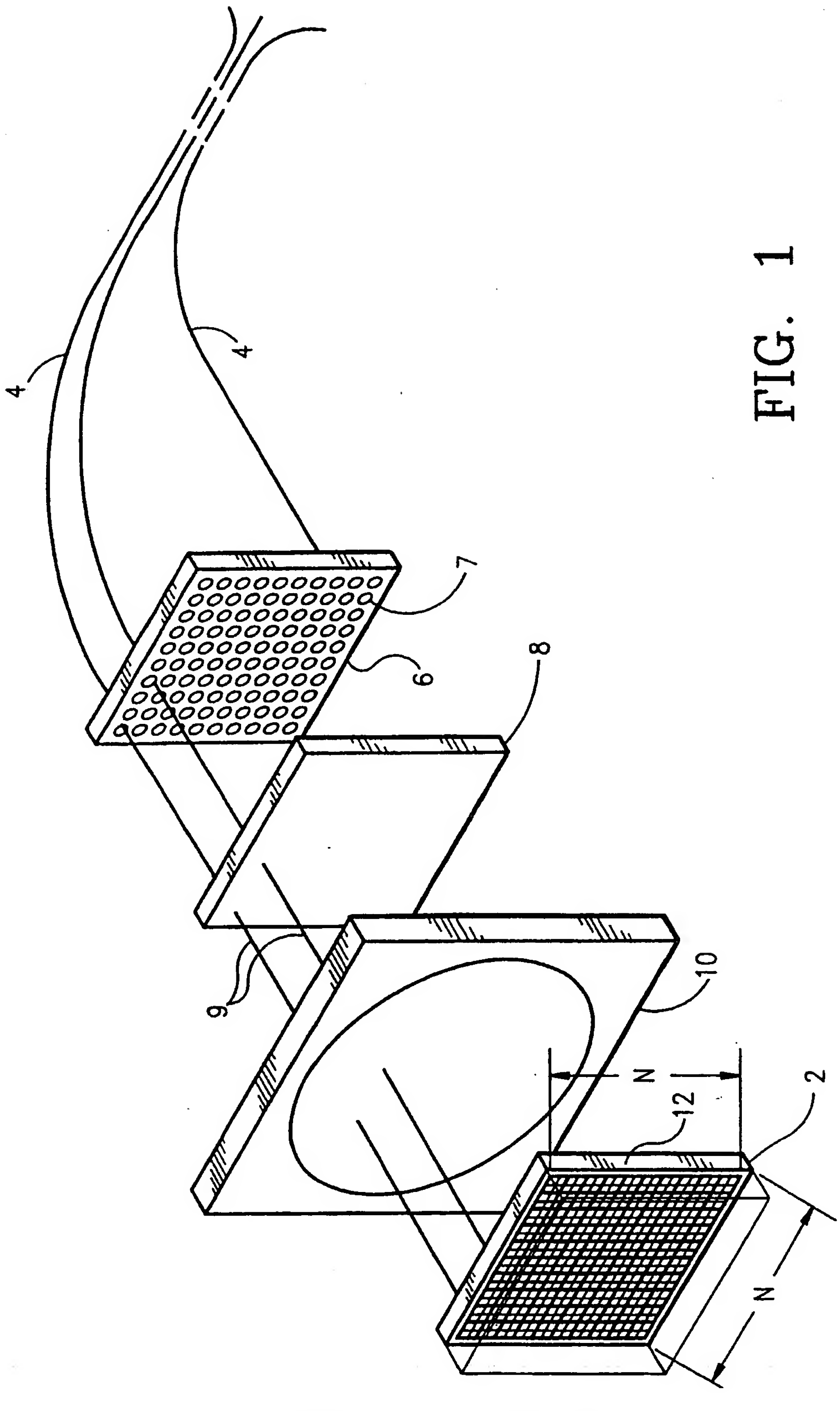

FIG. 1

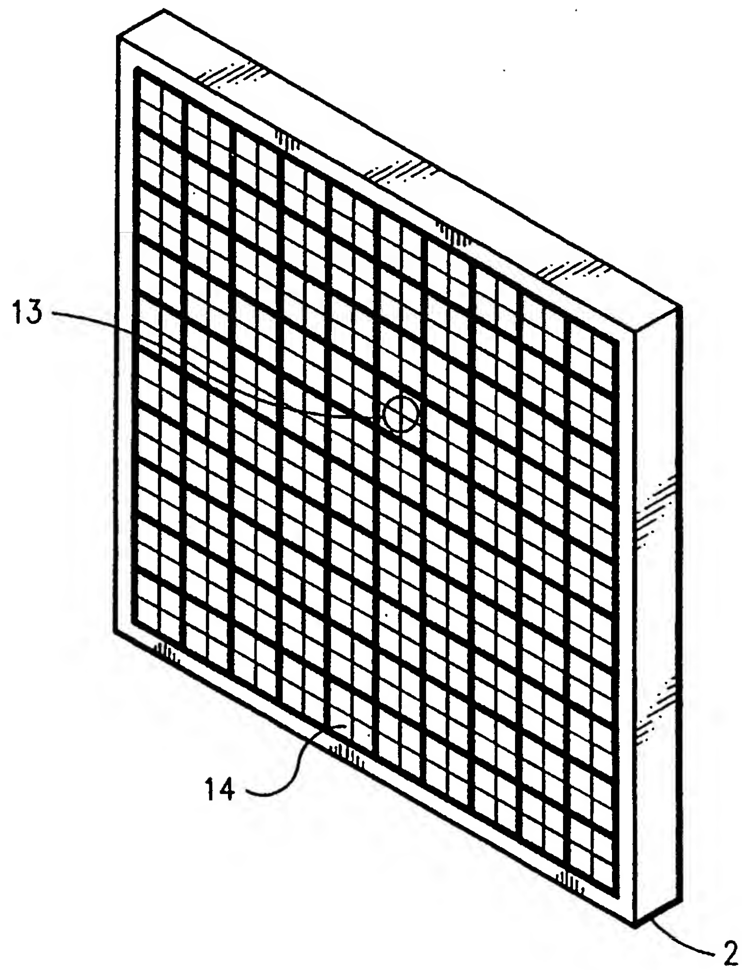

FIG. 2

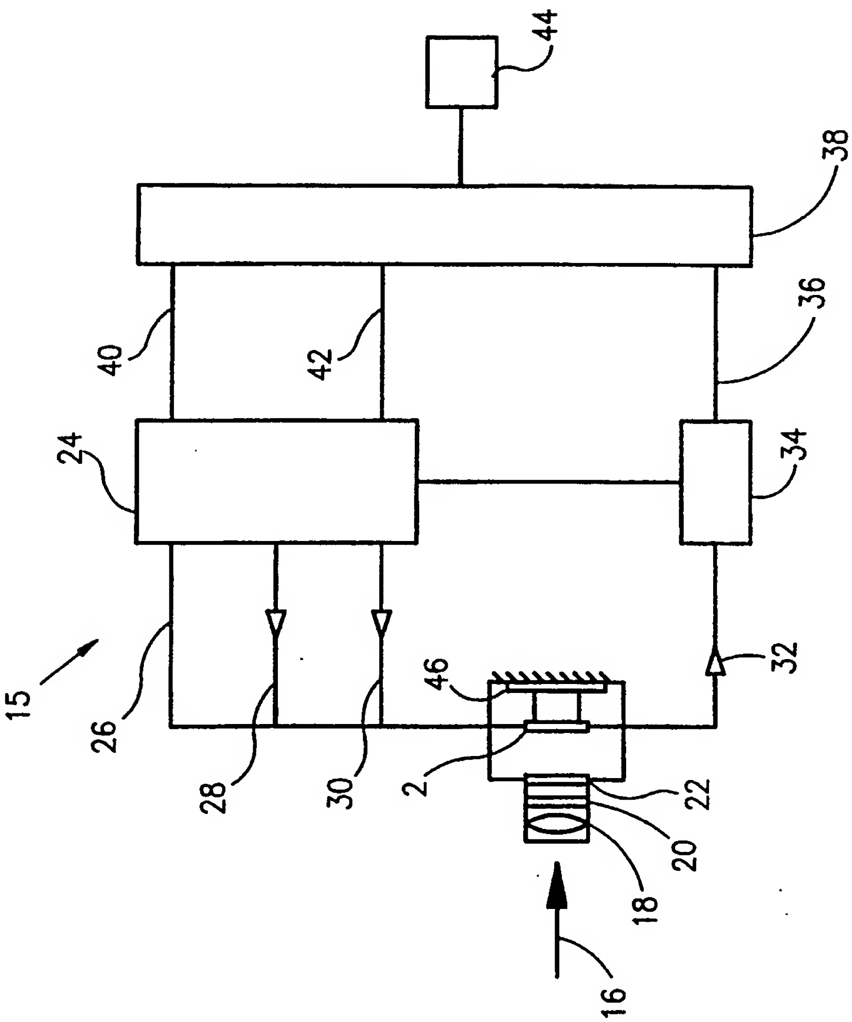

FIG. 3

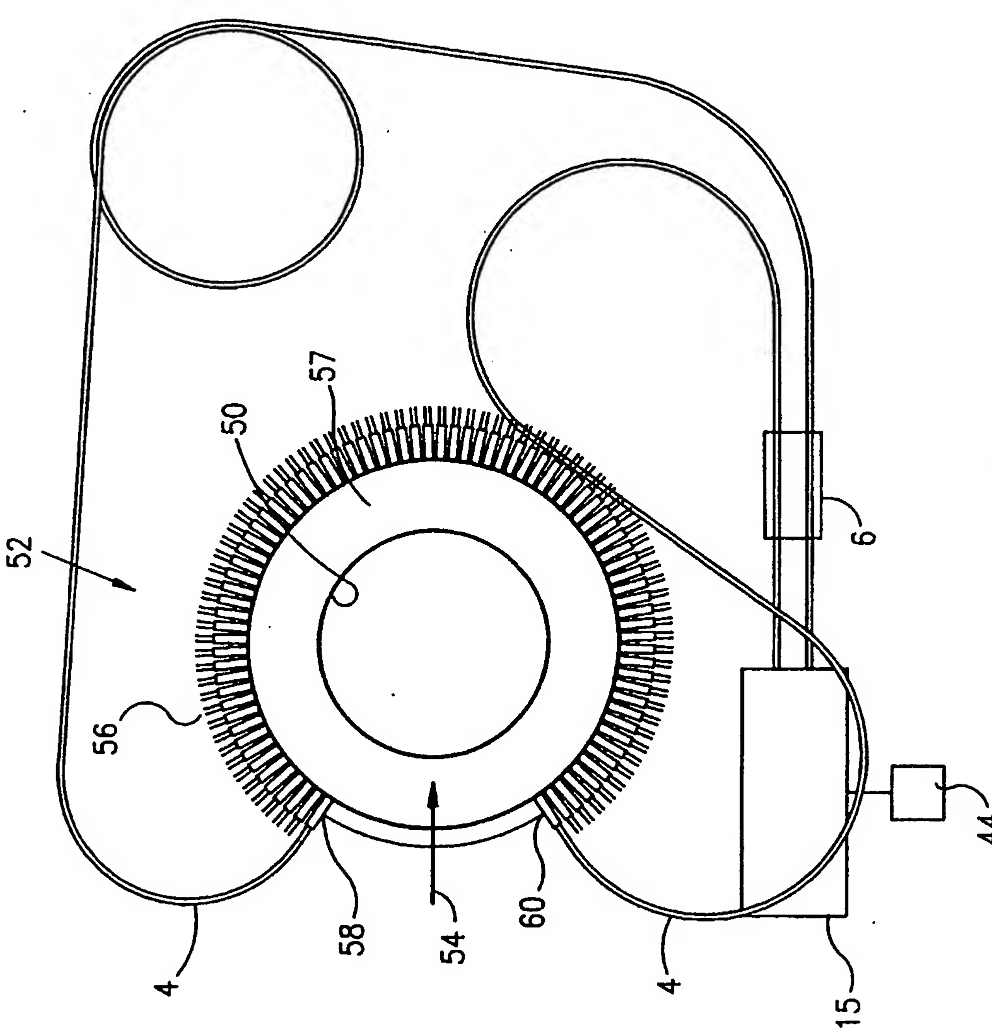

FIG. 4

36	9	17	25	33	41	49	57	65	73	REF
5	13	21	29	37	45	53	61	69	77	81
3	11	19	27	35	43	51	59	67	75	83
7	15	23	31	39	47	55	63	71	79	2
6	14	22	30	38	46	54	62	70	78	4
10	18	26	34	42	50	58	66	74	82	8
12	20	28	1	44	52	60	68	76	84	16
24	32	40	48	56	64	72	80	*	*	*

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/00516

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :A61B 1/04; H04N 3/02, 5/225; G01N 21/64; F21K 2/00
US CL :348/45,65,68,197,216,217; 250/461.1, 461.2, 459.1
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 348/45,65,68,197,216,217; 250/461.1, 461.2, 459.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P -- Y,P	US 5,952,664 A (WAKE ET AL) 14 September 1999, see col. 4	5, 15, 17-18 ---------- 1, 3-4, 6-7, 9-14, 19-20
X -- Y	US 5,824,269 A (KOSAKA ET AL) 20 October 1998, see col. 5.	2 ------- 1, 3-4, 6-11, 14, 16, 19-20
Y,P	US 5,986,271 A (LAZAREV ET AL) 16 November 1999, see col. 5.	9-10
Y	US 5,436,655 A (HIYAMA ET AL) 25 July 1995, see figure 10.	1, 6, 8, 11-13,

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 22 MAY 2000	Date of mailing of the international search report 04 AUG 2000
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer ALICIA M.HARRINGTON Joni Hill Telephone No. (703) 308-9295

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

CORRECTED VERSION

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
10 August 2000 (10.08.2000)

PCT

(10) International Publication Number
WO 00/46979 A3

(51) International Patent Classification[7]: A61B 1/04, H04N 3/02, 5/225, G01N 21/64, F21K 2/00

(21) International Application Number: PCT/US00/00516

(22) International Filing Date: 4 February 2000 (04.02.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/118,745 5 February 1999 (05.02.1999) US

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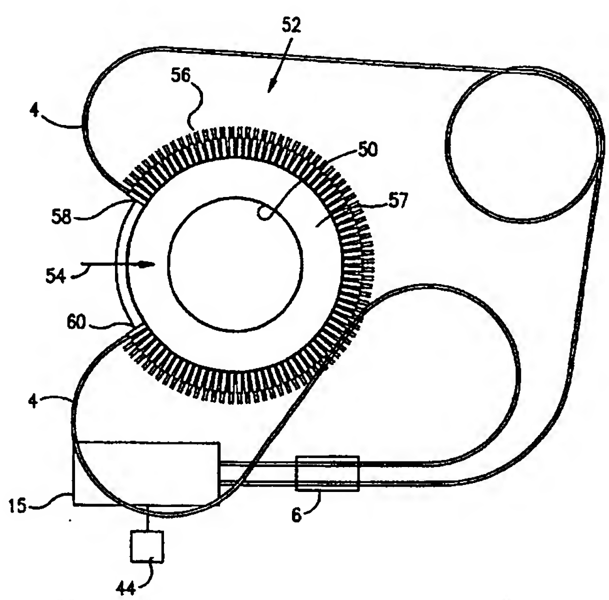
(81) Designated States *(national)*: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

[Continued on next page]

(54) Title: CCD ARRAY AS A MULTIPLE-DETECTOR IN AN OPTICAL IMAGING APPARATUS



(57) Abstract: A scanner assembly for a laser imaging apparatus comprises a plurality of collimators (56) disposed in an arc around an opening in which an object to be scanned is disposed; a plurality of fiber optic cables (4), each having one end being associated with a respective collimator; a light tight enclosure; and a CCD array disposed within the enclosure (15) and disposed at the other ends of the fiber optic cables to detect light picked up by the collimators and transmitted by the fiber optic cables.

WO 00/46979 A3

(88) **Date of publication of the international search report:** 30 November 2000

(48) **Date of publication of this corrected version:** 30 August 2001

(15) **Information about Correction:** see PCT Gazette No. 35/2001 of 30 August 2001, Section II

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

CCD ARRAY AS A MULTIPLE-DETECTOR IN AN OPTICAL IMAGING APPARATUS

FIELD OF THE INVENTION

The present invention relates to optical imaging apparatus and more particularly to imaging devices that use a charge-coupled device(CCD).

BACKGROUND OF THE INVENTION

Charge-coupled devices (CCD's) can be be individual devices or, more commonly, individuals cells or pixels arranged in an array, either as a linear array or as a X-Y matrix. With a suitable optical lens, the CCD is commonly used as a sensor for video cameras. The CCD usually has a spectral response in the visible region, 400-700nm, and typically extends into the near infrared region, 700-1100nm.

Conventional usage primarily focuses on using the CCD as the sensing element of a video camera that produces an electronic image of a field of view. The interval between refreshing the CCD array and sampling the accumulated charge is sometimes referred to as the integration interval. In typical video formats, the integration interval is the result of the vertical frame rate, typically 50 or 60 times per second for an integration interval of 20 and 16.7 milliseconds(ms) respectively.

In some imaging situations, the level of light that is available is extremely low. There are several devices that convert radiant energy into electrical energy. Conventional

sensors for low light levels are photomultiplier tubes(PMT) and micro channel plates(MCP) that provide amplification by secondary emission of electrons. In a PMT, a photosensitive cathode releases electrons when photons impinge upon it, i.e., photoemission. The positive bias applied to the elements of a PMT, the dynodes, attract the negative charge electrons, e^-, emitted by the photocathode. When the electrons strike the dynodes, they cause a secondary release of addition electrons, i.e., secondary emission. These additional electrons subsequently strike dynodes that have a higher positive bias and release additional electrons. This avalanche effect continues until the final dynode is involved. The avalanche causes an amplification of the single photon striking the photocathode. Typically, a 12-stage photomultiplier has an amplification of approximately 17 million. A single photon results in the release of approximately 17 millions electrons. The pulse has a time duration of approximately 5 nanoseconds resulting in a peak current flow of approximately 1 milliampere.

The micro channel plate amplifies the single photon event in a similar manner. Very small diameter holes are fabricated into a plate and then coated with a conductive material. The effect is similar to a PMT. Electrons enter the holes and dislodge other electrons which in turn dislodge even more electrons. The net result is that a single electron initiates an avalanche of electrons and signal amplification occurs. When used alone or in cascade, signal gains of 10^4 to 10^7 are achieved with temporal resolution of approximately 100 picoseconds. Spatial resolution is limited by the channel

spacing, typically 9μm-diameter channels on 10μm centers. Resolution of this type of design is approximately 16 line pairs/mm. The anode side of the MCP is coated onto the inside of a glass envelope and is made of a photoemissive material. When the accelerated photons impinge on the coating a flash of light is given off.

In a MCP CCD array, the CCD element is coupled to the anode end of the MCP and light flashes are directed to the pixels in the CCD array. A signal as small as a single photon can result in a detectable event. In some designs two MCP's are cascaded to more than double the sensitivity of the CCD system. The CCD array is fabricated with parallel conducting strips in one direction and p^+ channel stops at right angles. Electron-hole pairs are created when light is incident on the p-type silicon. The charges, representing picture-element signals, are stored in potential wells under depletion-biased electrodes, i.e., the picture elements(pixels) in the array. The charges are transferred by applying a positive pulse to the adjacent electrodes. The whole image is transferred to a storage raster. Each horizontal line is read out of the storage raster in sequence to provide an output signal. It is possible to read the signal from individual pixels, and this is desirable under certain circumstance.

The rate at which the data is read out from a CCD array has important ramifications. If the CCD is not read for a long length of time and the incident light is very weak, the stored charge will increase over time and a usable image can result.

While an array of PMT's could be fabricated to emulate the detection capabilities of an intensified CCD, there are physical considerations that make this approach unattractive. One advantage of an intensified CCD is the small size required for the detector area. A large number of pixels can be fitted into an area less than one-square centimeter. If a bundle of fiber optic cables are placed in front of the MCP input face and an appropriate lens is used to focus the light emitted by the fiber optic cables, a large number of individual fiber optic cables can be monitored by as small as a single pixel per fiber in the array. Because there are hundreds of pixels--512 x 512 pixels are not uncommon--a significant number of individual fiber optic cables can be coupled to a single detector array.

Thus the present invention describes an apparatus and method for using a single CCD array as a detector for one single photonic event as seen by a single input fiber optic cable or significantly more than one photonic event can be monitored by the array.

OBJECTS AND SUMMARY OF THE INVENTION

It is an object of the present invention to use a CCD or an image intensified cooled CCD array as a detector for photonic events occurring in the visible and near infrared portions of the spectrum.

It is another object of the present invention to use a lens to couple the light emerging from a bundle of fiber optic cables onto the input face of an image intensifying device placed in front of a cooled CCD array.

It is another object of the present invention to use a single image intensified cooled CCD array as a detector for one or a plurality of detectors for individuals events.

It is another object of the present invention to use a single image intensified cooled CCD array as an integrating detector whereby photonic events separated in time can be acquired by a single detector array.

In summary, the present invention provides a scanner assembly for a laser imaging apparatus, comprising a plurality of collimators disposed in an arc around an opening in which an object to be scanned is disposed; a plurality of fiber optic cables, each being associated with a respective collimator; and a CCD array disposed at the other ends of the fiber optic cables to detect light picked up by the collimators and transmitted by the fiber optic cables.

These and other objectives of the present invention will become apparent from the following detailed description.

BRIEF DESCRIPTIONS OF THE DRAWINGS

Figure 1 is a schematic perspective view of a detector assembly in accordance with the present invention, showing a CCD array with a N x N matrix of pixels, a focusing lens, an optical filter, a manifold for holding the fiber optic bundle and a bundle of fiber optic cables.

Figure 2 is schematic perspective view of a CCD array showing a portion being illuminated by a ray of light.

Figure 3 is a schematic block diagram of a CCD camera including an electronic circuit to control and read a CCD array.

Figure 4 is a schematic view of a data acquisition system using one or more fiber optic cables to couple light collected by individual collimators positioned as an array encircling a breast in an optical scanning application.

Figure 5 is an arrangement of the ends of the fiber optic cables at the CCD array.

DETAILED DESCRIPTION OF THE INVENTION

An assembly R for using a CCD array 2 as a photodetector in a computed tomography laser mammography apparatus is disclosed in Figure 1. Light collected from a scanning chamber is transmitted by a plurality of fiber optic cables 4 held together by a suitable manifold 6 to position the fiber optic cables 4 in a specific pattern in front of the CCD array 2. The manifold 6 is a support comprising a matrix of holes 7 each adapted to receive and support therein a fiber optic cable 4. Light rays 9 emitting from the ends of the fiber optic cables 4 are directed to the CCD array 2. Optical filters 8 may be used to selectively tune the wavelengths transmitted by the optic fibers before they impinge on the CCD array 2. A single filter 8 can be used for the whole set of bundle of fiber optic cables instead of a single filter for each fiber. The filter 8 may be a bandpass filter to pass only the desired range of wavelengths. The filter 8 may also be a cutoff filter to pass only the desired range of wavelengths greater or less than a cutoff wavelength. The filter 8 is used in fluorescence imaging, as disclosed in U.S. Patent No. 5,952,664. A lens 10 may be used to focus the light from the optic fibers onto the CCD array 2. The lens 10

may be eliminated where the fiber bundle is placed very close to or in contact with a micro channel plate (MCP) 12 used in conjunction with the CCD array 2.

The CCD array 2 comprises individual cells or pixels 14 arranged in an array, either as a linear array or as X-Y matrix. Referring to Fig. 2, a light ray from an optic fiber 4, represented by a footprint 13, illuminates four pixels. The number of pixels illuminated can be controlled by the use of the lens 10. Changing the lens 10 can reduce or expand the number of pixels illuminated. The choice of the lens 10 allows for an area as small as a few pixels, or as large as the area covered by all of the pixels to be illuminated. Each element or pixel of the CCD array acts as an individual sensor responsive to light emitting from a fiber optic cable. The light intensity as seen by the sensor is read and used to reconstruct an image of the object being scanned.

A standard CCD camera 15 used in the present invention is disclosed in Fig. 3. Incoming light 16 transmitted by the fiber optic cables 4 is directed to an optic lens 18 that distributes the incoming light unto the CCD array 2. A shutter 20 can be used to control the light radiating on the CCD array 2. A window seal 22 provides a light-tight enclosure. A camera control logic and power supply 24 is used to control the CCD array 2. DC voltage 26, serial clock drive signals 28 and parallel clock drive signals 30 are connected to the CCD array 2. A low noise preamplifier 32 is used to amplify the CCD pixel signals. An analog processing and analog-to-digital conversion is provided by block 34. Pixel output data 36 is coupled to a computer interface circuit 38,

which is a high precision video frame grabber, such as that available from La Vision Gmbh, Goettingen, Germany, Pico Star High Resolution - Product Imager. The camera control logic and power supply 24 provides a camera status signal 40. The computer interface circuit 38 provides camera commands 42. The circuit 38 provides the interface between a computer 44 and the CCD array 2. The computer 44 is used to manipulate the CCD information to create an image of the breast as seen by the CCD array. The computer 44 can also extract information from only selected pixels within the CCD array. The CCD array 2 is cooled by a thermo-electric cooler 46 or other suitable coolers. A charge intensified device (CID) or ceramic metal oxide semiconductor (CMOS)array, cooled or intensified, may be used in lieu of the CCD array.

Referring to Fig. 4, in a typical breast scanning application, a breast (not shown) is to be suspended in an opening 50. A laser scanner 52 comprises a source of laser beam 54 for impinging on the breast. Light exiting from the breast is picked up by the collimators 56 directed to the areas of the breast from which light is exiting. The collimators are disposed in an arc around the breast and supported by a structure 57 rotatable 360 degrees about an axis centered on the opening 50 center. The fiber optic cables are identical in length and provide enough slack to allow the rotation of the structure 57. Each collimator is coupled to a fiber optic cable. The scanner, including the collimators 56 and the laser beam 54, is rotated as a unit around the breast in steps through several equal angular displacements until a complete circle is traversed. At each

angular position, the collimators pick up any light exiting from the breast and couple the light to the respective fiber optic cables. The group of fiber optic cables 4 is held by the manifold 6. The fiber optic cables 4 direct the light unto the micro channel plate 12 of a CCD array 2 forming the input to the MCP CCD camera 15. The computer 44 processes the light detected by the camera to generate an image of the breast.

The fiber optic cables 4 are arranged in the manifold 6 such that adjacent fiber ends at the collimators are not adjacent at the other end at the CCD array. This arrangement is designed to provide minimum cross-talk between the fibers. In a laser imaging apparatus using 84 detectors, each being associated with a respective collimator and fiber optic cable, where collimator 56 is designated as detector 1 and collimator 60 is detector 84, an example of an arrangement of the ends of fiber optic cables at the CCD array is disclosed in Fig. 5. Note that adjacent fibers at the collimator end are not adjacent at the manifold 6.

Use of collimators in a laser imaging apparatus is described in application serial no. 08/963,760, filed November 4, 1997, hereby incorporated by reference. Use of fiber optic cables to transmit light captured by the collimators to remote detectors is described in application serial no. 09/199,440, filed November 25, 1998, hereby incorporated by reference. Examples of laser imaging machines are disclosed in U.S. Patent No. 5,692,511 and application serial no. 09/199,440, hereby incorporated by reference. A method for reconstructing an image from data provided by an array of detectors is

described in application serial no. 08/979,624, filed November 28, 1997, hereby incorporated by reference. Determination of the perimeter of the breast being scanned, which is used in image reconstruction, is described in application serial nos. 08/965,148 and 08/965,149, hereby incorporated by reference.

While this invention has been described as having preferred design, it is understood that it is capable of further modification, uses and/or adaptations following in general the principle of the invention and including such departures from the present disclosure as come within known or customary practice in the art to which the invention pertains, and as may be applied to the essential features set forth, and fall within the scope of the invention or the limits of the appended claims.

We claim:

1. A scanner assembly for a laser imaging apparatus, comprising:

a) a plurality of collimators disposed in an arc around an opening in which an object to be scanned is disposed;

b) a plurality of fiber optic cables, each having one end being associated with a respective collimator;

c) a light-tight enclosure; and

d) a CCD array disposed within said enclosure and disposed at the other ends of said fiber optic cables to detect light picked up by said collimators and transmitted by said fiber optic cables.

2. A scanner assembly as in claim 1, wherein:

a) said CCD array includes a micro channel plate.

3. A scanner assembly as in claim 1, and further comprising:

a) a support to position said other ends of said fiber optic cables in front of said CCD array in a pattern.

4. A scanner assembly as in claim 3, wherein:

a) said support is a manifold including a matrix of holes to receive therein a respective fiber optic cable.

5. A scanner assembly as in claim 3, wherein:

a) said other ends of said fiber optic cables are arranged in such a way that adjacent ends at said collimators are not adjacent at said support.

6. A scanner assembly as in claim 1, and further comprising:

a) a lens disposed between said CCD array and said

other ends of said fiber optic cables to focus the light from the other ends of said fiber optic cables onto said CCD array.

7. A scanner assembly as in claim 1, and further comprising:

a) a lens disposed between said CCD array and said other ends of said fiber optic cables to focus the light from the other ends of said fiber optica cables onto a selected portion of said CCD array.

8. A scanner assembly as in claim 1, and further comprising:

a) a filter disposed between said CCD array and said other ends of said fiber optic cables.

9. A scanner assembly as in claim 8, wherein:

a) said filter is a bandpass filter.

10. A scanner assembly ad in claim 8, wherein:

a) said filter is a cutoff filter.

11. A scanner assembly for a laser imaging apparatus, comprising:

a) a plurality of collimators disposed in an arc around an opening in which an object to be scanned is disposed;

b) a plurality of fiber optic cables, each being associated with a respective collimator; and

c) a CCD camera operably disposed at the other ends of said fiber optic cables to detect light picked up by said collimators and transmitted by said fiber optic cables.

12. A scanner assembly as in claim 11, and further comprising:

a) a support to position said other ends of said

fiber optic cables in a pattern into an optic of said CCD camera.

13. A scanner assembly as in claim 12, wherein:

a) said support is a manifold including a matrix of holes to receive therein a respective fiber optic cable.

14. A scanner assembly for optical imaging, comprising:

a) a plurality of collimators disposed in an arc around an opening in which an object to be scanned is disposed;

b) a plurality of fiber optic cables, one end of each being associated with a respective collimator;

c) a support to secure the opposite ends of said fiber optic cables in a pattern; and

d) a CCD camera operably disposed at the other ends of said fiber optic cables to detect light picked up by said collimators and transmitted by said fiber optic cables.

15. A scanner assembly as in claim 14, wherein:

a) said other ends of said fiber optic cables are arranged in such a way that adjacent ends at said collimators are not adjacent at said support.

16. A method for collecting data for use in image reconstruction of an object being scanned with a laser beam, comprising:

a) providing a laser beam directed to the object being scanned;

b) providing a plurality of collimators disposed in an arc around the object to be scanned to collect light radiating from the object;

c) providing a plurality of fiber optic cables, one

end of each being associated with a respective collimator;

d) bundling together the opposite ends of the fiber optic cables;

e) providing a CCD array to take an image of the bundled ends of the fiber optic cables; and

f) using the image on the CCD array to reconstruct an image of the object.

17. A method as in claim 16, wherein:

a) said bundling is implemented such that adjacent fiber optic cables at the collimators are not adjacent at the other ends.

18. A method as in claim 16, wherein:

a) said bundling is implemented with a manifold to hold the other ends of the fiber optic cables in a pattern.

19. A method as in claim 16, wherein:

a) the fiber optic cables are equal in length.

20. A method as in claim 16, wherein:

a) the CCD array comprises a part of a CCD camera.

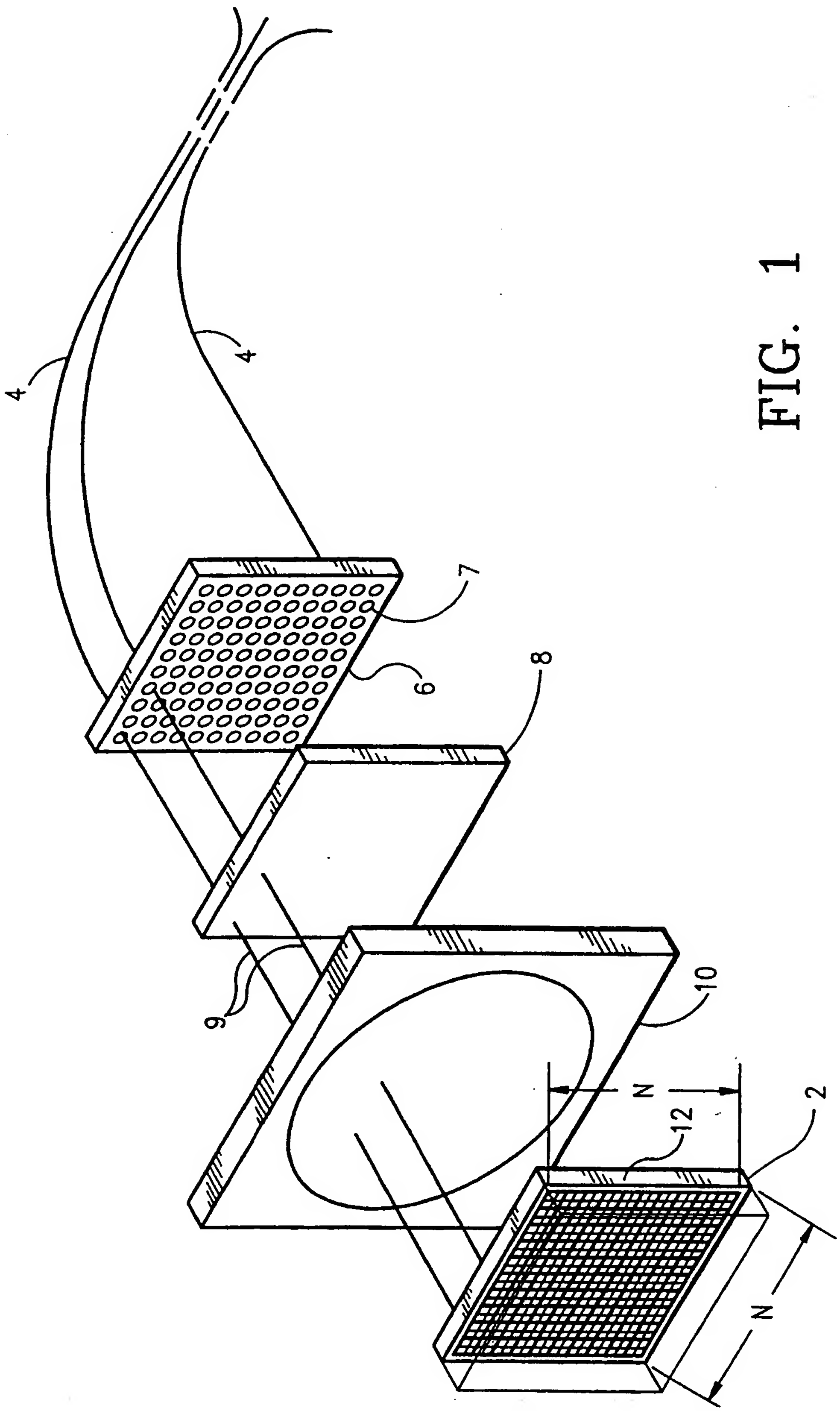


FIG. 1

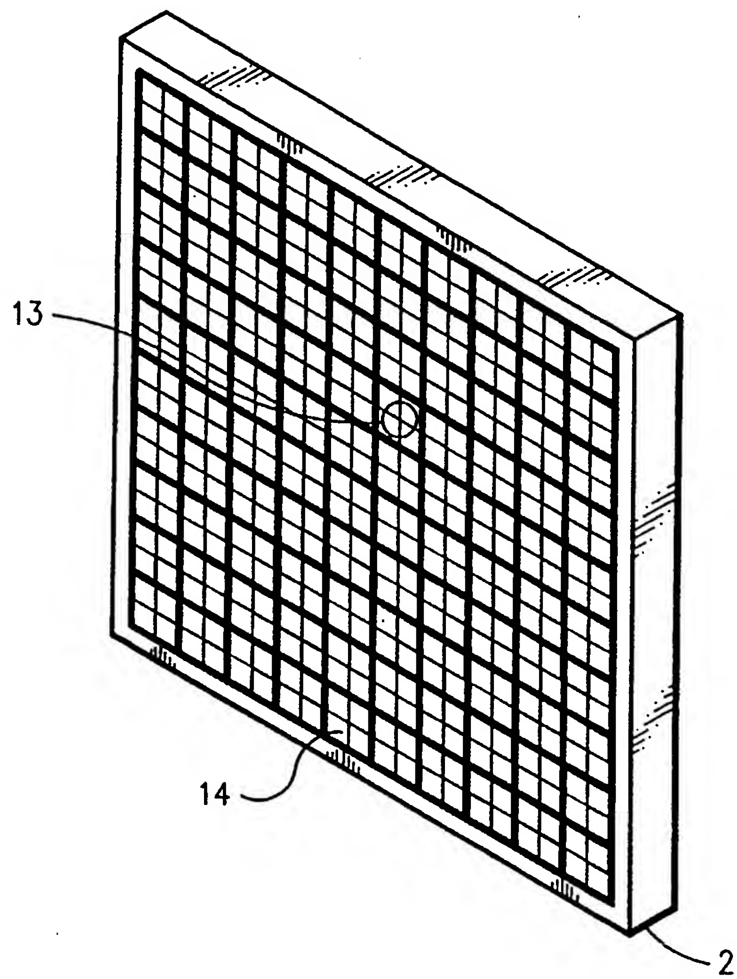


FIG. 2

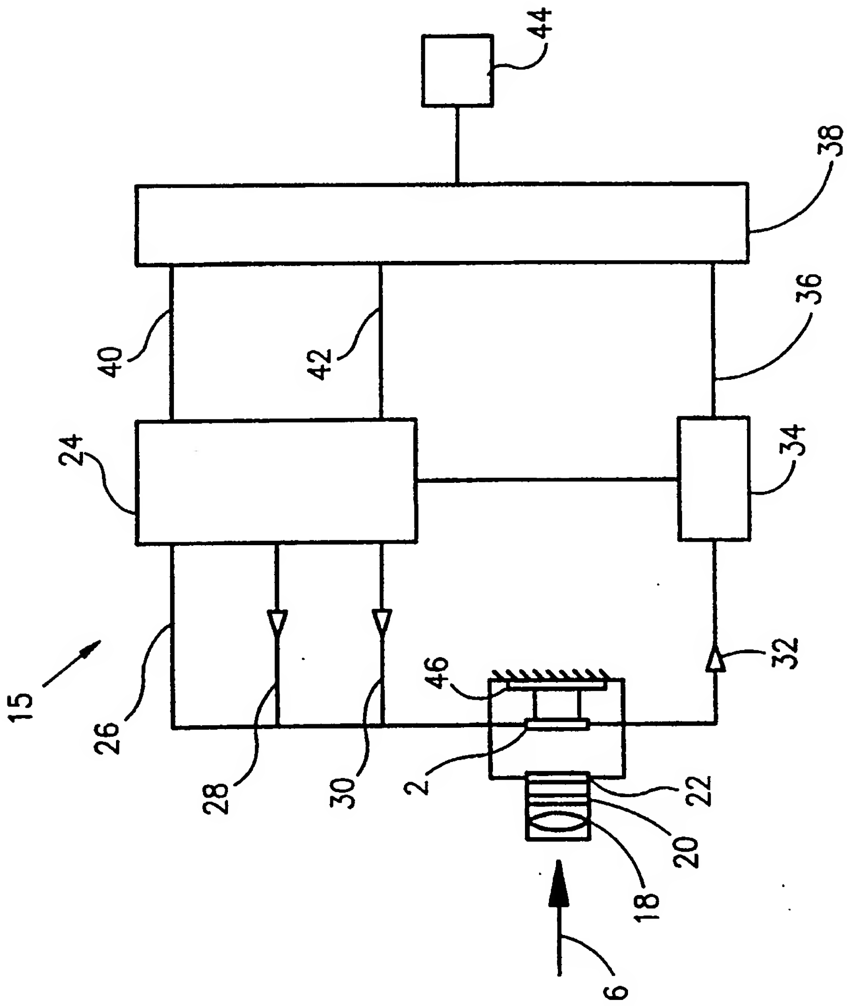


FIG. 3

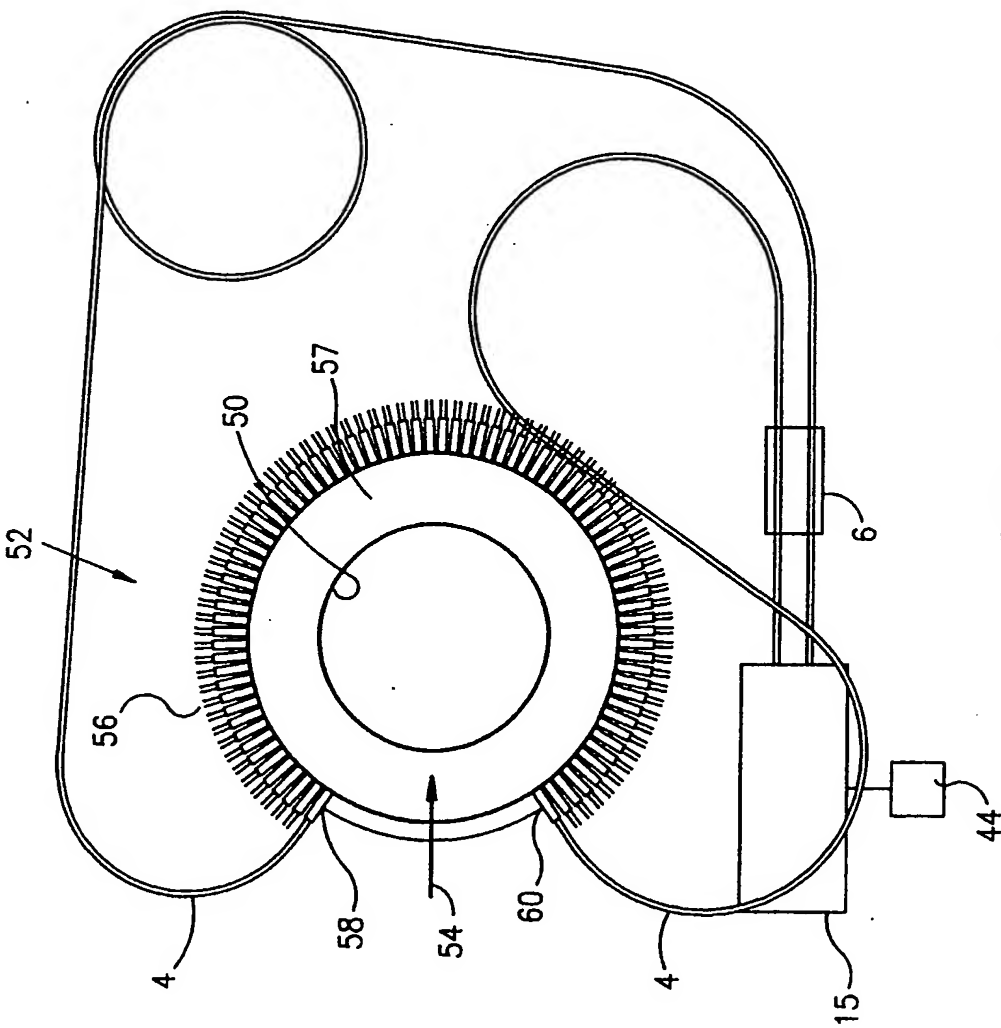


FIG. 4

36	9	17	25	33	41	49	57	65	73	REF
5	13	21	29	37	45	53	61	69	77	81
3	11	19	27	35	43	51	59	67	75	83
7	15	23	31	39	47	55	63	71	79	2
6	14	22	30	38	46	54	62	70	78	4
10	18	26	34	42	50	58	66	74	82	8
12	20	28	1	44	52	60	68	76	84	16
24	32	40	48	56	64	72	80	*	*	*

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/00516

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :A61B 1/04; H04N 3/02, 5/225; G01N 21/64; F21K 2/00
US CL :348/45,65,68,197,216,217; 250/461.1, 461.2, 459.1
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 348/45,65,68,197,216,217; 250/461.1, 461.2, 459.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P -- Y,P	US 5,952,664 A (WAKE ET AL) 14 September 1999, see col. 4	5, 15, 17-18 ----------- 1, 3-4, 6-7, 9-14, 19-20
X -- Y	US 5,824,269 A (KOSAKA ET AL) 20 October 1998, see col. 5.	2 -------- 1, 3-4, 6-11, 14, 16, 19-20
Y,P	US 5,986,271 A (LAZAREV ET AL) 16 November 1999, see col. 5.	9-10
Y	US 5,436,655 A (HIYAMA ET AL) 25 July 1995, see figure 10.	1, 6, 8, 11-13,

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	
"E" earlier document published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	"&" document member of the same patent family

Date of the actual completion of the international search 22 MAY 2000	Date of mailing of the international search report 04 AUG 2000
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer ALICIA M.HARRINGTON Joni Hill Telephone No. (703) 308-9295

Form PCT/ISA/210 (second sheet) (July 1998)★